Electron-Mediated Nuclear Reactions

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1. Premises

1.1. The Electron Zitterbewegung

The electron manifests as a point charge with a perfectly symmetric electric field, but the charge behaviour is governed by some more complex features. The so called Dirac Equation, which is the best description of the electron we have, says that the electron has an intrinsic and very fast rotation, the so called Zitterbewegung (ZB), a German word that means "trembling motion". The frequency of this rotation is very high: 2.47E20 [Hz], so much that it is almost impossible to measure it.

Actually the Dirac equation describes the evolution in 4D (Minkowski Space) of the plane where the rapid rotation of the point charge takes place (see ref. [1] in which the apparatus of "Geometric Algebra" is used). What is commonly defined as the speed of the electron combines with the rapid ZB giving a spiralling motion.

The only value that makes sense for the speed of the electron point charge along the ZB trajectory is the speed of light.
The point charge trajectory would be perfectly circular for an hypothetical electron at rest.
The diameter of the rotation is fixed and is much larger than any nucleon: about 386 [fm].
The intrinsic spin, the magnetic dipole moment and other properties of the electron are consequences of this very rapid rotation.

1.2. The Nuclear Force is Electromagnetic

The force that keeps the nucleons together in any nucleus is short-ranged and has a highly quadrupolar nature, in the sense that it strongly depends on the reciprocal orientations of the spins/magnetic dipoles. Therefore this force apparently looks quite different from all well known electromagnetic "forces".
However Norman Cook and Valerio Dallacasa proposed in the 1980's a theory which suggests that the nuclear force has an electromagnetic origin. This theory was recalled in a more recent article: "LENR and Nuclear Structure Theory" presented at ICCF-17 by Cook and Dallacasa (ref. [4]). In this article the authors say: "We have found a fermi magnetic effect that is a microscopic version of the Biot Savart law of magnetic attraction between parallel currents". This magnetic effect originates from the phasing of the charge rotation inside nucleons. The energies are in the [MeV] range, which is compatible with the known nuclear binding energies, and all unusual properties of the nuclear force are present in this attraction. The authors suggest that the short-rangeness is essentially due to the lack of phasing for large distances.
My hypothesis about the "core secret" of LENR assumes that the attraction mechanism proposed by Dallacasa and Cook is not only correct for nucleons, but that under particular conditions it can act also between the electron and nucleons/nuclei. The electron therefore becomes a sort of "range extender" of the otherwise short-ranged nuclear force.

2. The LENR Reactions

The present theory describes the LENR as nuclear fusion reactions mediated by the electron.
They happen in **two stages**:

1. Firstly an **electron and a hydrogen isotope couple** through the attractive force of Dallacasa and Cook becoming a neutral "pseudo-particle", that I named Hydronium, Deuteronium and Tritioniuim, depending on the hydrogen isotope involved. Collectively I will use the name Hydronions (Hyd). In essence this pseudo-particle is made of a hydrogen nucleus "trapped" inside the circular potential well along the electron Zitterbewegung trajectory. The potential is generated by the same force that keeps nucleons together in all nuclei. I will explain this in more detail later in this text. The generation of this pseudo-particles is the hard part of the LENR game, that requires the very special conditions that made LENR so difficult to reproduce and control.
2. Secondly the **Hydronions**, being picometrically neutral, **can move freely inside matter and** eventually **penetrate any electronic shell, reaching the nucleus** of an atom/ion and couple with it through the same potential that keeps the Hyd together. Once the electron has hooked up along its Zitterbewegung the second nucleus as well, the two "captured" nuclei can move towards each other along the "electron round track" and gently meet. The contact of the two nuclei happens with almost no excess kinetic energy, and the daughter particles generated in the reaction tend to be mainly stable nuclides.

Randell L. Mills of BlackLight Power detected the presence of Hydronium in his experiments and named it Hydrino, suggesting that the particle was a "compact" form of the hydrogen atom. Since the present theory suggests that the particle has nothing to do with an atom of hydrogen, I prefered to give it a different name.

2.1. First Stage

The first stage of the LENR involves always the same particles, and is therefore simpler than the second stage in which many different nuclei can react. There are only three possible reactions that generate the three Hydronions:

```
 0p: p+e -> pe (Hydronium)  +   Gp [MeV]
 0d: d+e -> de (Deuteronium)+   Gd [MeV]
 0t: t+e -> te (Tritionium) +   Gt [MeV]
```

Gp, Gd and Gt stand for the different amounts of electromagnetic energy radiated by the forming Hydronions. I used the number 0 because these are the "Ground" reactions that allow the plethora of the other Second Stage reactions.

2.2. Second Stage

The second stage of the LENR has a much wider phenomenology.
Once the two nuclei trapped "along the ZB" meet, a series of possible reactions can take place:

With **Hydronium (ep)**:

```
 (p1)  Nu(Z,A) + ep -> Nu(Z,A+1)   + neutrino     + photons
 (p2)  Nu(Z,A) + ep -> Nu(Z+1,A+1) + e            + photons
```

With **Deuteronium (ed)**:

```
 (d1)  Nu(Z,A) + ed -> Nu(Z,A+2)   + neutrino     + photons
 (d2)  Nu(Z,A) + ed -> Nu(Z+1,A+2) + e            + photons
 (d3)  Nu(Z,A) + ed -> Nu(Z,A+1)   + ep           + photons
?(d4)  Nu(Z,A) + ed -> Nu(Z+1,A+1) + e + n        + photons
```

With **Tritionium (et)**:

```
 (t1)  Nu(Z,A) + et -> Nu(Z,A+3)   + neutrino     + photons
 (t2)  Nu(Z,A) + et -> Nu(Z+1,A+2) + e            + photons
 (t3)  Nu(Z,A) + et -> Nu(Z,A+2)   + ep           + photons
 (t4)  Nu(Z,A) + et -> Nu(Z,A+1)   + ed           + photons
?(t5)  Nu(Z,A) + et -> Nu(Z+1,A+1) + e + 2n       + photons
```

Clearly Nu(N) is a nucleus with atomic number Z and nucleon number A.
Immediately after the reaction the newly formed nucleus could undergo other nuclear reactions.
The three equations with number 1 (p1, d1 and t1) are **ternuclear** reactions in the sense that three particles react at the same time because they meet in the same place. This type of reaction is almost absent in the very much studied plasma that everyone associates with nuclear fusion.

A question mark has been put in front of the reactions (d4) and (t5), because it is well possible that these two reactions in which the Hydronions abandon the proton do not take place.

When only hydrogen isotopes react with Hydronions, the possible reactions are:

```
1e : p+ep              ->d   + neutrino + (max)     1.442[MeV] - Gp
2e : p+ed              ->t   + neutrino + (max)     5.475[MeV] - Gd
3e : d+ep              ->t   + neutrino + (max)     5.475[MeV] - Gp
3  : d+ep              ->He3 + e +                  4.472[MeV] - Gp
4e:  d+ed+0.141[MeV]+Gd->H4  + neutrino +           0.00 [MeV]
                     H4 ->t   + n +                 3.391[MeV]
4.1: d+ed              ->He4 + e  +                22.825[MeV] - Gd
4.2: d+ed              ->t   + ep +                 4.033[MeV] - Gd + Gp
5e : t+ep+4.174[MeV]+Gp->H4  + neutrino +           0.00 [MeV]
                     H4 ->t   + n +                 3.391[MeV]
5  : t+ep              ->He4 + e +                 18.792[MeV] - Gp
6e : t+ed+5.318[MeV]+Gd->H5  + neutrino +           0.00 [MeV]
                     H5 ->t   + 2n +                2.311[MeV]
6.1: t+ed              ->He5 + e +                 15.832[MeV] - Gd
                    He5 ->He4 + n +                 0.735[MeV]
6.2: t+ed+5.616[MeV]+Gd->H4  + ep                   0.00 [MeV] + Gp
                     H4 ->t   + n +                 3.391[MeV]

7  : t(beta decay)     ->He3 + e + antineut. + (aver)  5.7 [KeV]
```

He3 can turn into He4 in presence of Hydronium or Deuteronium with these reactions:

```
8e : He3+ep            ->He4 + neutrino + (max)   19.80 [MeV]
9  : He3+ed            ->He4 + ep       + (max)   20.58 [MeV]
```

If the reactions involve two Hydronions (it should be a rare event) the reactions are the same as above, apart from one electron more in the daughters and "less released"/"more required" energy (bold parts):

```
1eh: ep+ep             ->d   + e + neutrino + (max)1.442[MeV] - Gp - Gp
2eh: ep+ed             ->t   + e + neutrino + (max)5.475[MeV] - Gp - Gd
3eh: ed+ep             ->t   + e + neutrino + (max)5.475[MeV] - Gp - Gd
3h : ed+ep             ->He3 + e + e +              4.472[MeV] - Gp - Gt
5eh: et+ep+4.17[MeV]+Gp+Gt->H4+e + neutrino +       0.00 [MeV]
…
5h : et+ep             ->He4 + e + e +             18.792[MeV] - Gp - Gt
etc.
```

The reactions that involve the electron have been named with an e after the reaction number. In these cases a neutrino is emitted because the electron on the left disappears. As I will motivate later, these reactions, if their counterparts where the electron does not participate are (nuclearly) possible, become much less likely.

Reactions 4e, 5e, 6e and 6.2 produce free neutrons, but they need some additional amounts of energy to take place.
The list above does not include the reactions with et (Tritionium).
It is interesting to note that if Gp is higher than 1.442 [MeV], reaction 1e does not take place without the contribution of some additional electromagnetic radiation. I anticipate here (I will mention it again) that the radiation measurement results of the experiments of Iwamura Y. et al. in ref. [7] seem to suggest that Gp is 1.745 [MeV]. If this value is correct reaction 1e requires as much as 303 [keV] to take place. I will mention this when commenting on the results of the Hot-Cat test (ref. [6]).
Reactions 2e, 3e and 4.2 generate tritium without producing free neutrons.
Reaction 5 consumes tritium and releases a large amount of energy.
Reaction 4.2 produces Hydronium. If then Hydronium separates into proton and electron, this reaction becomes a source of protons. So in case of deuterium loading this reaction should be responsible for the appearance of protium. This should be the source of the molecular hydrogen in the experiments of Yoshino, Igari and Mizuno (see ref. [1]).
In case of hydrogen loading the most common reactions are 1e and 2e.
In case of deuterium loading the most common reactions are 4.1 and 4.2. Reaction 4.1 produces much more energy than reaction 4.2 and liberates tritium and Hydronium (that, as already mentioned can become protium).
The reactions with number 6 (6.1 is the only not requiring additional energy) are rare, apart from cases where tritium has accumulated together with deuterium. However accumulating tritium should not happen (I will explain why later).
The only beta decay is that of tritium.
Reactions 4.1 and 5 are significantly more energetic than the rest because they produce He4.
The only other reactions producing He4 are 6.1 and 8e, which are rarer than the other two.
This is the reason why the excess energy has been easily correlated with the production of He4.

The question now is:
How can possibly an hydrogen nucleus and one electron couple so as to form a neutral pseudo-particle inside a metal matrix?

2.3. Dallacasa's Magnetic Attraction Makes the Trick

The attractive potential between two nucleons that Dallacasa and Cook describe comes from the Lorentz force that a circularly rotating charge feels when invested by the oscillating magnetic field generated by another phased rotating charge. This potential has the following series development, valid for y>>R:

[1] $$V(y) = \frac{\mu_0}{\pi} \frac{m_{mag2}}{r_2} \frac{m_{mag1}}{r_1 y} cos(\varphi) + o(y^2)$$

where:

- m_1 and m_2 are the magnetic dipole moments of two nucleons,
- r_1 and r_2 are the corresponding charge radii (imagining that a single point charge rotates around the centre of the particles at these distances),
- φ is the fixed phase between the two rotating charges,
- y is the distance between the centres of the two nucleons.

When the force was firstly described by Dallacasa and Cook it was meant for explaining only the nuclear force. However the attractive magnetic force manifests only to two facts:

- the charges of the particles rotate
- the rotations are synchronized (fixed phase).

2.3.1. The Electron Feels the Same Force

The electron, which has its intrinsic ZB, in the case of a rotation frequency identical to the nucleons' rotations, should be subject to the very same attractive force. In other words it is possible that the attractive force that Dallacasa and Cook say manifests between nucleons, manifests as well between a nucleon and an electron.
The attractive magnetic force becomes then the necessary "gate" for accessing the LENR reactions listed above.

2.3.2. The Hydrogen Nuclei are Captured by the Electron

Essentially, in particular conditions, the electron can couple with a hydrogen isotope and "capture" it inside its Zitterbewegung orbit. The very special conditions seem to be possible almost only inside some metal matrices. The electron gets squeezed towards a hydrogen nucleus with its magnetic moment aligned; when the distance between the electron and the hydrogen isotope reaches down to a few picometers the attractive potential of Dallacasa and Cook can prevail over the "electron orbital repulsion". Clearly the short distance is not the only necessary condition for the "capture" to happen.
Before going into the details of the collapse mechanism, let me describe first how I think the hydrogen isotope and the electron can be squeezed so close as to reach the critical condition for the formation of Hyd. This is the "physical chemistry" part of the theory and is not really using any unusual ingredient. The mechanism is probably not unique and could happen in slightly different ways.

2.4. Fist Stage: How Hydrogen and Electron are Forced to Form Hydronions

The Nuclear Active Environment (NAE) of Edmund Storms (ref. [10]) is necessary only for the First Stage reactions, namely for the generation of the Hyd, while the Second Stage, thanks to the neutrality of the Hyd, does not require a special environment.
Experiments suggest that Hyd can form in different ways, not only inside a metal matrix heavily loaded with hydrogen isotopes; however this is the way Hyd are formed in most LENR experiments.
My experience with hot metals tells me that the "solid state NAE" can not be, as Storm suggests, a special shape/size crack, because any initially present crack structure can not survive the localized high power demonstrated by the LENR. In addition any crack in a metal has a "thickness" that is much larger than the internuclear distance of the metal structure. And at that scale nothing happens.
I suggest instead that the NAE is simply a moving vacancy near to the surface of active grains.
The First Stage LENR are therefore sustainable only if there is a continuous vacancy movement. This is one of the reasons for the relative rarity of the LENR phenomenon, since keeping a sufficient number of vacancies in movement is not a common and easily controllable condition in the experiments.
When a metal is highly loaded with hydrogen isotopes (above 0.7 atomic ratio) it can develop a stable Superabundant number of Vacancies (SAV) that can ensure a sufficient density of NAEs.

2.4.1. Metal Particle Size Requirement

As Brian Ahern clearly explains, the very much discussed requirement for a specific metal "particle" size comes from the fact that the non-harmonic "large amplitude small frequency vibration modes", can concentrate large amounts of energy in specific locations of the crystal only if the particle size lies inside a specific range: 3 to 12 nanometers. These locations are near to the metal surface, where the crystal vibrations face "reflective" boundary conditions.

2.4.2. Dislocations Versus Vacancy Movement

An important additional (actually related) reason for the need of very small grains is that when the grains are larger than 10 [nm] the number of dislocations present inside the grains rapidly grows so high that the movement of dislocations captures the energy preventing it to go into the necessary vacancy movement. The well known and verified Hall Petch relationship comes from the fact that the presence of piled dislocations near to the surface of metal grains increases the yield stress of polycrystalline metals. The smaller the grain size in comparison to the "dislocation size", the higher the yield stress. However there is a critical size (commonly considered around 10 [nm]) below which the strengthening disappears because the number of dislocations drops to near zero.

The need for careful annealing of "LENR grade" palladium after cold rolling is due precisely to this reason. In fact cold rolling tends to elongate the grains and decrease their size, which is something positive; but it also tends to fill grains with the maximum possible number of dislocations, and this is not good because, as already mentioned above, dislocations can "steal the scene" to vacancy movement. Careful annealing of cold-deformed palladium allows then to decrease the number of piled dislocations without increasing the grain size.

2.4.3. Detailed Approach Mechanism Hypothesis

When one of the vacancies begins to move, a volume in which the electron density is lower "opens" behind the moving nucleus. This initially very small "cavity" attracts immediately positive charges from the surroundings, where a sufficiently high number of interstitial hydrogen nuclei are waiting.

If the energy concentration arrives in the right moment around the forming vacancy it can violently squeeze neighbouring interstitial hydrogen nuclei out towards the opening vacancy.

The forming "cavity" has a lower negative charge density and at least one electron binds to a hydrogen nucleus that is accelerating towards the centre of the cavity. The bound electron forms a tight s-type orbital, well before the hydrogen nucleus reaches the center of the forming vacancy. The orbital is tight because the space with less negative charge density is very small. Another hydrogen nucleus begins moving from its interstitial location towards the same forming vacancy without a bound electron. The two (or more) hydrogen nuclei are in collision course. While approaching, the bare hydrogen nucleus does not see the full charge of the other, because of the shielding of the tight electron orbital, hence it is not slowed down significantly in the approaching phase.

When the distance between the bare and the "shielded" hydrogens is already much smaller than in an H_2 molecule (less than 75 [pm]) the bound electron wave function would normally transform into something similar to a sigma bonding orbital squeezed far from its minimum energy. The hydrogen nuclei would then rapidly slow down in their approach and bounce back. But before this can happen, thanks to the low distance and the special features of the opening vacancy (the NAE), the electron manages to couple to the bare hydrogen nucleus through the magnetic attraction of Dallacasa and Cook.

One of the important conditions for the coupling is the alignment of the spins of the hydrogen nucleus and the electron spin. The magnetic field necessary for the alignment is either provided by the metal matrix, or by an external current.
Another important condition is the relative speed between the electron and the hydrogen nucleus, which has to reach very low values, as will be explained later in the text.
When the coupling prevails over the formation of a sigma electron orbital, the electron accelerates towards the hydrogen nucleus emitting photons and eventually the two particles form a Hydronion.
Probably the dynamics and the shape of the forming cavity play an important role in the Hydronion formation.

2.4.4. Hydrogen Molecules Formation

When the magnetic force does not succeed in overcoming the "orbital repulsion", it is likely that the two hydrogen nuclei will form a molecule. Therefore this theory predicts that there should be a correlation between the energy produced and the formation of hydrogen molecules inside the metal matrix (near to the surface of the active grains).

2.4.5. Magnetic Coupling Passing Unnoticed

If real, the magnetic coupling described probably passed so far unnoticed because in more common conditions either the spins of the two particles are not aligned, and the kinetic energy that forces them within a distance of tens of picometers is much higher than in this case.
In addition if any Hyd is created, the radiated energy is generally covered by much more energetic components and the produced particles are so far undetectable, because there are no instruments that can detect/measure their presence.

2.5. The Attractive Magnetic Force with Lightlike Particles

Let us now follow in detail the description of the attractive magnetic force, as described by Dallacasa and Cook, to which some assumptions will be added.
The first assumption Dallacasa and Cook make is that the magnetic dipole moment (m_{mag}) of a particle is generated by a single circularly rotating pointwise charge:

[2] $m_{mag} = \frac{1}{2} gqr \wedge v = \frac{1}{2} gqrv$.

In this formula q is the charge, g is the g-factor of the particle, r the radius of the rotating charge and v its speed. The last equation is due to the fact that r and v are supposed to be and remain orthogonal. Equation [2] can be written also in this way:

[3] $qv = \frac{2m_{mag}}{gr}$

If the charge trajectory is lightlike, (v = c), the radius of the rotating charge becomes:

[4] $r = \frac{2m_{mag}}{gqc}$

The corresponding frequency is then:

[5] $\omega \left[\frac{rad}{s}\right] = \frac{c}{r}$.

In the case of an electron, equation [5] leads exactly to the well known Zitterbewegung circular frequency of $1.55 \cdot 10^{21}$ [rad/s] ($2.47 \cdot 10^{20}$ [Hz]) and equation [4] to the radius of 193 [pm], commonly called *Electron Compton Wavelength*.
In the case of a nucleon, things get more complex. The total rotating charge is different from the particle charge, and the g-factors assume a somehow different meaning.
Considering however the proton as a single rotating charge equal to *e* (one electron charge and not 5/3*e* as the sum of the quark charges would suggest), equations [4] and [5] lead to a circular frequency of $4.54 \cdot 10^{23}$ [Hz], and a corresponding radius of about 0.105 [fm]. The ratio between this proton frequency and the electron Compton frequency is exactly equal to the proton-electron mass ratio: 1,836.152 .... Probably this happens by definition. The same reasoning for the neutron (with a charge of 1*e*) gives practically the same ratio (given the involved constant precisions).
Now the magnetic field generated by the rotating charge of a particle (1) is evaluated at a point R_{12}, which lies in the same plane of the rotation, using the so called Biot-Savart Law with no relativistic correction:

[6] $$B_1 = \frac{\mu_0}{4\pi} \frac{q_1 v_1 \wedge |R_{12}|}{{R_{12}}^2}$$

where R_{12} is the radius at which the magnetic field has to be evaluated and $|R_{12}|$ is the unit vector in the direction of R_{12}. The relativistic correction of this magnetic field without the radiation term (particles are stable), provided one can decide the speed to use for the Lorentz factor, does not give significantly different results apart from entering the realm of ultrarelativistic speeds. My guess is that the nature of the particles (ZB for the electron) is so that the rotating magnetic field around them corresponds to the non relativistically corrected field, despite the fact that the point charges travel at the speed of light.
Here we will assume that the particles move in the same plane of their charge rotation. In reality this clearly does not happen, at least at the incipit of the approach. Moreover every particle in a magnetic field precedes, and this has not been considered. However these corrections should not spoil the main argument.
Using equation [3]:

[7] $$B_1 = \frac{\mu_0}{4\pi} \frac{2m_{mag1}}{g_1 r_1} \frac{|v_1| \wedge |R_{12}|}{{R_{12}}^2} .$$

The Lorentz force on a second particle (2) caused by the first particle (1) is:

[8] $$F_2 = q v_2 \wedge B_1 .$$

Dallacasa's force acting on the second particle is hence:

[9] $$F_2 = \frac{2m_{mag2}}{g_2 r_2} \frac{\mu_0}{4\pi} \frac{2m_{mag1}}{g_1 r_1} |v_2| \wedge \frac{|v_1| \wedge |R|}{R^2} = \frac{\mu_0}{\pi} \frac{m_{mag2}}{g_2 r_2} \frac{m_{mag1}}{g r_1} |v_2| \wedge |v_1| \wedge |R_{12}| \frac{1}{{R_{12}}^2} .$$

F is not always directed from the center of one particle to the centre of the other, and a cosine has to be added to filter the "up and down perturbations".

Equation [9] says that the attractive force is proportional to the product of the magnetic moments of the two particles divided by the respective radii and by the gyromagnetic ratios. However, if equation [3] is valid for protons and neutrons because the charges inside them travel at the speed of light, the force of equation [9] becomes simply proportional to the charge of the particles (multiplied by *c*). In this way the only difference between the "rotating" magnetic fields generated by proton and neutron would be their total rotating charges. My guess is that for the neutron the g-factor does not play the same role as for the electron, but I am not able to suggest anything different.
The force of Equation [9] manifests only for phased rotations and has a quadrupole nature, in the sense that it depends strongly on the reciprocal orientations of the magnetic moments. This means that if the magnetic moments of the two particles are not aligned (and the rotation phased) the force can even become repulsive.

2.6. Electron - Hydrogen Coupling

As already mentioned, the ratio between the proton and the electron intrinsic frequencies seems to be equal to the ratio of their masses (p/e): 1,836.1527... [Hz]. This means that as soon as an electron is seen by a hydrogen isotope rotating at a frequency near 2 [kHz], the attractive magnetic potential of Dallacasa for the electron-hydrogen nucleus pairs reaches its maximum. It would be interesting to know if the reaction rate is sensitive to radio frequencies in the [kHz] range (a very low frequency). In atomic physics terms this frequency and the corresponding speeds are extremely low, practically zero. So probably one of the secrets of the NAE is the ability to force the hydrogen speed as high as the speed of the electron. And "electron speeds" (without entering the debate on the existence of such a concept in quantum mechanics …) of valence electrons are in the range of a few thousand kilometers per second.
The numbers seem to say that this force can overcome the "orbital repulsion" at a distance of a few picometers, provided the magnetic moments of the involved particle are kept "parallel" (apart from precession) by a magnetic field.
The radius of the electron Zitterbewegung is about 193 [fm], therefore much larger than any nuclear particle.
At the end of the approach the hydrogen nucleus actually crosses the ZB radius. Inside this radius the magnetic potential between electron and hydrogen nucleus becomes repulsive, therefore the hydrogen nucleus gest confined inside a narrow circular (helical) potential well as shown in Fig. 1. In the case of a proton, its rotation speed along the electron ZB trajectory should be equal to the p/e mass ratio. This would give an extremely low speed, around $2.23 \cdot 10^{-9}$ [m/s].
Due to the large difference in the masses of an hydrogen nucleus and the electron, the actual picture should be more similar to the electron in a circular orbit that sort of "precesses around" an almost still hydrogen nucleus.

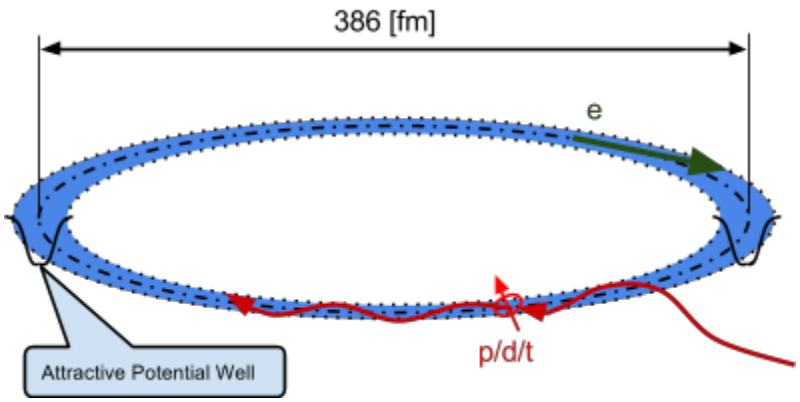

Fig. 1. A Hydronion with the potential well and the hydrogen nucleus approaching and becoming bonded.

The hydrogen nucleus can only move along the ZB trajectory.
The picture shows a perfectly circular ZB trajectory whereas in reality the trajectory is a helix. However, since the average electron speed (it is not something rigorous) in the s-orbital of an hydrogen atom is more or less equal to the speed of light divided by the fine structure constant (137), the ZB helix is often very narrow (has a small ratio between pitch and radius).
The potential well exists as long as the hydrogen nucleus rotates, relative to the electron ZB centre at the coupling frequency (as already mentioned, in the case of a proton or neutron the frequency is equal to the p/e mass ratio).

2.7. The Hydronion Can Move Freely Inside Matter

Since the maximum charge displacement vector between the electron point charge and the hydrogen nucleus charge is only 386 [fm] and the pulsation frequency is in around 10^{21} [Hz], the Hydronions behave as almost electrically neutral. This means that they are able to travel inside matter easily, without being significantly slowed or deviated either by the negatively charged electron orbitals or by the positive electric fields of the nuclei.
By the way, only a neutral particle can penetrate the electronic shells and and reach all the not so light nuclei that have been proven to undergo LENR (like Cs) without generating a shower of X and gamma photons.
The Hyd are probably not stable, in the sense that if they are hit by a sufficiently energetic photon, they should irreversibly separate into an electron and a hydrogen nucleus, possibly forming a hydrogen atom.

2.8. Second Stage: The Second Nucleus is Captured

If a Hyd reaches a nucleus, it can again couple with it through the attractive magnetic force, provided the nucleus emits an oscillating magnetic field. This for sure happens if the nucleus has a magnetic dipole moment, but also other higher magnetic moments can work at shorter distances.
As for the First Stage couplings, while the nucleus and the Hyd accelerate towards each other, they emit photons losing part of the final binding energy. In this Second Stage the range of the coupling is longer because there is no mechanism opposing the attraction, provided the magnetic moments are aligned and the two rotations can synchronize.
If the second coupling between a Hyd and a nucleus takes place, both trapped nuclei are forced to move along the electron ZB track.

2.9. The Two Captured Nuclei Approach and React

Once the two nuclei (one of which is a hydrogen isotope) are captured inside the electron ZB orbit, with their magnetic moments oriented, the attractive magnetic force between them is stronger than the electrostatic repulsion and the two "captured" nuclei accelerate towards each other as shown in Fig. 2.

The exact way in which this approach takes place should be investigated through numerical simulations in order to understand it in more detail.

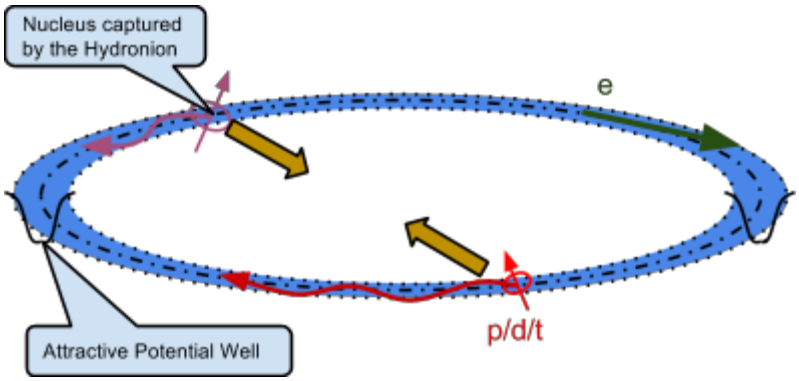

Fig. 2. A captured nucleus inside the Hydronion and the hydrogen nucleus attract each other.

2.9.1. Participation of the Electron and Emission of a Neutrino

If the rotating electron passes through the two nuclei right while they are near enough to be reacting, the nuclear fusion can involve the electron as well, and the reaction becomes ternuclear. However a nuclear reaction takes place in roughly 10^{-22} [s], which is only about 2.5% of the time the electron needs to turn once around its ZB orbit. Thus the reactions involving the electron should be significantly less likely than their counterparts in which the electron is not involved, provided that the latter are possible.

Sometimes the ternuclear reaction is the only reaction that can take place, as in the case of reactions 1.e and 2.e.

Since the present theory assumes that the force keeping nuclei together is purely electromagnetic, all LENR in which the electron does not participate would involve only the electromagnetic interaction. The ternuclear reactions instead involve the weak interaction and entail the emission of a neutrino.

2.9.2. Preference for Stable Nuclei

All Second Stage fusions take place with an almost nil excess kinetic energy, very differently from the high kinetic energies typical of hot fusion, necessary for overcoming the coulomb barrier in absence of electron mediation.

Therefore in the Second Stage LENR only the lowest energy and most stable nuclei can be "assembled". This could be the reason for the apparent preference of the LENR for the generation of stable nuclei.

2.10. Further Work is Necessary

This explanation is a crude simplification of what may happen in reality. In fact, among the applied simplifications are these:

- All precessions were neglected, despite probably being important,

- The transversal forces (orthogonal to the line connecting the point charges) were neglected,
- The particle accelerations are limited by their masses,
- The oscillating magnetic field "emitted" by the Hydronions has not been considered in detail to see how it can couple to the nuclei around while it travels across a metal matrix.
- The approach of the two nuclei in the Second Stage could be more complex than described because the interaction of the three charges suggests a more complex scenario.
- No Hamiltonian for the coupling was proposed,
- ...

However I think that the explanation proposed contains most of the essential features of the real coupling.
The first moves towards the theoretical verification of this theory could be a series of numerical simulation campaigns:

- Numerical simulation of the **buildup of nuclei with Dallacasa's force** using all possible details in order to verify if the proposed force can actually be responsible of most of the binding energy.
- Numerical simulation of a formed **Hydronion** to verify if the proposed "pseudo-particle" has any chance to be **stable**.
- Numerical simulation of the metal matrix events that could lead to the **formation of a Hydronion**. Firstly with a simplified metal matrix and then with increasingly more features. This to verify if the proposed mechanism, or similars, are actually able to lead to the formation of Hydronions.
- Numerical Simulation of the **coupling of Hydronions to any other nucleus**.
- ...

2.11. Agglomeration: A Possibility?

Some LENR works suggest that there can be an agglomeration of Hydronions, possibly kept together by the magnetic attraction. This is a possibility that I have not considered in detail.

2.12. Magnetic Coupling

The evidence in the Report on the Hot-Cat (ref. [6] and [7]) is that the nuclei without a magnetic dipole moment can react as well. This means that the coupling between a Hydronion and a nucleus can take place for nuclei with zero magnetic dipole moment that however have higher order magnetic moments. Clearly any nucleus with zero magnetic moment can not be aligned by a magnetic field. This should decrease the reaction rate of these nuclei when compared with nuclei that have a magnetic dipole moment.
Some nuclei, like Ni62, do not to react at all. This should be due to the complete absence of any magnetic moment. These nuclei are therefore completely "LENR-proof".

2.12.1. Some comments about Ni62

This nucleus is made of 28 protons and 34 neutrons. The structure can be schematized as 7 cubic substructures with 4 protons and 4 neutrons each plus 6 neutrons. One of the 7 substructures stays in the centre and 6 all around the 6 faces. The 6 additional neutrons are then positioned all around as at the centre of the faces of a cube. This structure should be perfectly symmetric and have no magnetic dipole moment.

3. Physical Chemistry and Metallurgy of LENR

3.1. Hydrogen Loading Threshold

In Ni, Pd, Ti and other metals that can be heavily loaded with hydrogen isotopes, when the loading is sufficiently high the vibrational modes become strongly non-linear and the metal matrix swells significantly. In addition the number of vacancies, which are essentially the NAEs for the first stage reactions, grows with loading.
These two trends are responsible for the high loading threshold for the appearance of excess heat.

3.2. What is an Active Metal Particle?

By the expression "metal particle size" I do not mean what granulometry can measure, but something different, that can be much smaller. If the metal grain boundaries, or even the sub-grain boundaries are enough "reflective" for the vibrations (phonons), they can effectively define an active "metal particle" for LENR. The right size, as said, remains around a few nanometres.

3.3. Electromagnetic Stimulation of the Matrix Vibrations

If the metal particles that have the right size are excited not only with heat, but also with electromagnetic pulses, the localized energies peaks can rise even more. In addition, since the reaction rate can be increased by the presence of a strong magnetic field that keeps the magnetic moments aligned, the EM pulses can contribute as well to the LENR power by generating high magnetic fields.

3.4. LENR is a Surface Effect

I think that the description of LENR as a surface effect comes from four facts:

1. the energy localization starts already when only one of the three dimensions (along the layer thickness) is reduced to be equal or less than 10 [nm],
2. the reflective boundary conditions cause peaks in the vibrational energy at the particle surface,
3. The number of dislocations, which could absorb energy from the otherwise unique channel of vacancy movement, decreases significantly alaredy when only one dimension is reduced to equal or less than 10 [nm],
4. The vacancies accumulate near the surface of the metal particles.

3.5. Comments about Temperature

Metal hydrides can have a super abundant number of vacancies.
Since the number of vacancies in a metal grows non-linearly with the temperature, part of the non-linear increase in LENR power with temperature is due to the growth of the number of vacancies per unit of volume.
Above 150 [C] nickel undergoes rapid sintering, therefore the LENR active particles must have boundaries made with something different than nickel itself.
Up to 354 [C] nickel is ferromagnetic and generates a magnetic field that helps to keep the magnetic moments (and spins) aligned up to the "collision" of the three particles. Above that temperature only brute current through a coil would generate a high magnetic field.

The often reported need for high thermal flux for the initiation of the reaction is due to the increase in the vacancy movement in presence of high thermal gradients.

3.6. Comments about the Magnetic Field

An important condition for the "efficient" coupling is the presence of a strong magnetic field that keeps the precessing magnetic moments of the particles oriented in the same direction up to when the magnetic attraction can prevail.

3.7. Tritium Accumulation

As already stated above, equation [4] says that, if the point charges of the particles travel at the speed of light, the ratio m_{mag}/gr is equal to twice the charge times c: $2\ q\ c$. This means that the attractive potential of Equation [9] would differentiate the particles only by the total charge that in each contributes to the magnetic dipole moment. However all other nuclei , apart from protium, are made of bound "sub-particles", so that equation [4] can not be applied to them.

In the case of deuterium and tritium it would be necessary to guess an appropriate radius for the charge rotation.

If the "rotating charge radii" of deuterium and tritium are imagined to be equal to the radius used for the proton (0.105 [fm]), the attractive force between electron and deuterium becomes only 31% of the force between the electron and the proton. Instead the potential ratio between the t-e and the p-e pairs would be even higher than 1: about 1.07. This suggests that the formation of Hydronium and Tritionium should easyer than that of Deuteronium.

Moreover the sources of tritium, namely reactions 2e, 3e and 4.2 involve all deuterium, while the sinks of tritium, namely reaction 5, involve protium. Therefore the it seems that the destruction of tritium is faster than its generation.

This would answer Dr. Edmund Storms and explain why the E-Cat does not have problems with tritium accumulation.

3.8. Energy Fractionation

Assuming as in this theory that the nuclear force coincides indeed with the "magnetic force" of Dallacasa and Cook, my guess is that in hot nuclear fusion the mass difference (or magnetic energy) between mother and daughter nuclei manifests "suddenly" only at the femtometer scale because of lack of phasing for larger distances. When the two particles start phasing they are at approximately 2 [fm] distance, so that they can not accelerate and emit photons, forcing the magnetic energy to go only into the speed of the daughter particles without electromagnetic radiation. In LENR instead, the hydrogen and the other nuclei collapsing towards the electron have the chance to accelerate for some picometers and radiate electromagnetically most of their magnetic potential energy.

Inside a metal matrix, the presence of interactions levels, like those of Landau, break up the [MeV] energies into many soft-gamma photons of a few hundred [keV] or less. This is why the kinetic energy of the daughter particles of LENRs is not like that of hot fusion.

Therefore there is no need for a special mechanism for the energy fractionation that many researchers have been looking for so much. The LENR energy goes into dipolar soft gamma radiation due to particle accelerations.

If the magnetic field that orients the magnetic moments of the collapsing particles is macroscopically homogeneous the radiating energy should have a non-homogeneous angular distribution and be the result of many emitting dipoles oriented in any direction in the plane

orthogonal to the macroscopic magnetic field. Therefore there should be very low emission perpendicularly to the magnetic field. Interestingly, the majority of the radiation inside a solenoid as the tested How-Cat should in fact be directed along the axis of the solenoid.

3.8.1. Comment on Titanium

I think that Titanium is not a good LENR host because it fractionates the LENR energy in photons that can activate reactions that emit neutrons.

3.9. Differences Between Palladium and Nickel

In the palladium matrix the interstitial hydrogen nuclei distribute homogeneously (they sort of repel each other), whereas in a nickel matrix they clump/cluster together. So that even with a low average loading, in nickel there are zones which have high loading (above 0.7), together with zones with almost no loading at all. In nickel a loading above 0.7 is enough to stabilize the vacancies, whereas this does not happen in palladium. So in the case of nickel one could have the formation of active particles around a hydrogen source with the rest of the matrix remaining not active. In palladium it is instead necessary to load the whole metal matrix before the critical LENR condition can be reached. Ref [11], by Michael C. H. McKubre et al., shows that for palladium the minimum atomic loading is about 0.85. And loading palladium that much requires an electrolytic process.

3.10. No Coulomb Barrier to be Crossed

The present theory offers a mechanism that never requires the crossing of a Coulomb barrier. In fact in the generation of the Hyd (First Stage reactions), the involved particles have opposite charges and the magnetic attraction has to prevail only against the tendency of the electron to form orbitals around positive charges (ionization energies). In the Second Stage reactions the electrical neutrality of the Hyd allows them to get near enough to any nucleus and accelerate towards it thanks to the magnetic attraction.

3.11. Why Has the Magnetic Coupling so Far Passed Unnoticed?

The magnetic coupling that can generate Hydronions could have passed unnoticed because in more common conditions either the spins of the two particles are not aligned as inside a metal matrix, or the kinetic energy that forces them within a few picometers distance is much higher than in the LENR case.

4. Other Comments

4.1. About Robert Godes' Electron Capture Theory

I think that the theory of Robert Godes of Brillouin Energy Corp., namely that ultra cold neutrons are actually generated inside the lattice by "controlled" electron capture reactions, is impossible because the lepton number is not conserved in such reaction. Electron capture can happen only in larger nuclei. This reason alone suffices, however there are other additional reasons:

- As many noticed, the energy to form a neutron from a proton and an electron (782.33 [KeV]!) is too much for the dynamics of the lattice, even with anharmonic modes,
- Free neutrons appear experimentally only in "extreme", often uncontrollable and impulsive conditions, well after the onset of LENR.

4.2. Muon Catalyzed Fusion

The magnetic coupling does not take place significantly in muon catalyzed fusion because in that case it is the mass of the muon (207 times the electron mass) that binds "as usual" the two hydrogen nuclei to less than 500 femtometres with random spin orientation. The thermal molecular vibrations seem make the rest.

5. Additional Tests for the Theory

5.1. Influence of Radio Frequencies

Radio frequencies in the very low frequency range, particularly around 2 [kHz] could be able to influence the formations of Hydronions.

5.2. Neutron Emission Stimulation

One test for the proposed reactions is the stimulation of neutron production via gamma rays. In fact the reaction 4e says that if the NAE is irradiated with photons having an energy of 0.141[MeV] + Gd the production of neutrons should be activated. As explained later in the text, the measurements of Iwamura seem to suggest that Gd is equal to 1.445 [MeV], so that the activation of neutron emission should start from an energy of 1.586 [MeV].
A similar argument is valid also for equations 5e, 6e and 6.2.

5.3. Tritium Elimination

The authors of ref. [8] say: "We are strongly tempted to suggest that there is an as yet unidentified mechanism periodically 'cleansing' the electrolyte of tritium".
As mentioned before it seems that the rate of depletion of tritium should be higher than that of its generation, especially in absence of significant gamma radiation. Therefore the LENR should be able to provide a way to destroy tritium.

5.4. Vacancy Movement Stimulation

Stimulating the charge with photons that enhance the movement of vacancies should raise the reaction rate. This when the size of the grains is small enough to have a very low number of dislocations than could interfere hindering the vacancy movement.

6. Analysis of the Hot-Cat Test Results

6.1. Isotopic Analysis

The ICP-AES sample was 0.21% of the total powder and ash. Since the powder is a mixture of grains of different origin, the sample could well be not representative of the whole population. In fact Jean Pettersson, author of the ICP-MS and ICP-AES analyses, says on page 53:"*Only a few granules of grey sample were possible to obtain from the ash and they didn't look exactly the same. One large and two very small granules were observed*".
So the total content of Li7 and Ni may well have been significantly different from the measured values: 0.0117 [g] (1.17% of the charge powder) for Li and 0.55 [g] for nickel.
The LENR should happen only on the surface of the active grains. Even with small grains that have a few nuclei along their radii, the fraction of nuclei that can be involved is not 100%. This means that it should be impossible to have an isotopic enrichment of Ni62 or Li6 up to 100%. Part of the Ni and Li should remain at the natural isotopic ratios. In the test instead the

measured enrichment in Ni62, both with the SIMS and with the ISP-MS, is near to 100%. The reason could be the fact that at 1,400 [C] the metal grains of which the active particles are made of undergo not only grain growth, but also recrystallization, activated by the gamma and the kinetic energy of the "not too fast" daughters of the LENR. So that sooner or later all Ni nuclei are invested by the LENR.
All ToF-SIMS spectra seem to show non-natural isotopic ratios. One for all: what is the strong signal at mass=43 in the upper graphs of Fig. 11 on page 52? A smaller and visibly separate ion signal seem to be present, but what is the non-ion signal? Ca43 is quite rare in natural Calcium (0.135%).

6.1.1. Absence of Deuterium and Tritium

The SIMS excluded the possible presence of deuterium and tritium in the ash.
If reaction 1e is correct, in presence of Hydronium and the loaded and measured protons, some deuterium should develop and be detectable in the hydrides after shutting down the experiment. However, as it was already mentioned before in this text, if Gp is higher than 1.442 [MeV], reaction 1e would require energy to take place. In fact the radiation measurement results of the experiment of Iwamura Y. at al. in ref. [7] seem to suggest that Gp is 1.745 [MeV]. If this value is correct reaction 1e was not taking place during the measured Hot-Cat test because of lack of significant radiation around 303 [keV].
Without deuterium there are no reactions that can produce tritium, namely 2e, 3e, 4e, 5e, 6e and 6.2. This is essentially the reason for the lack of tritium in the ash.

6.2. Energy Balance

The measurements say that the Hot-Cat emitted around and not less than 1.5 [MWh], which is equal to $3.37 \cdot 10^{22}$ [MeV].
Let us assume that the quantity of nickel in the fuel is as estimated by the ICP-AES: 0.55 [g]. The number of nickel nuclei of mass 58, 60 and 61 (all the forward shifting) present in the fuel are respectively: $3.842 \cdot 10^{21}$, $1.48 \cdot 10^{21}$, $6.433 \cdot 10^{19}$. These values can be obtained using the natural isotopic ratios of Nickel. So the total number of unitary (A+1) forward shift reactions necessary to transform all Ni58, 60 and 61 into Ni62 would be $3.376 \cdot 10^{22}$.
Forgetting about lithium, if the measured emitted energy, $3.37 \cdot 10^{22}$ [MeV], is divided by the number of shifts, $3.376 \cdot 10^{22}$, one obtains the apparent average energy of a unitary nickel isotopic forward shift: about 1 [MeV]. This is is a particularly low value for this type of reactions. Moreover, if the isotopic lithium shifts were added, the average energy value would decrease even more. This already strongly suggests some inconsistency between the measured energy, the isotopic and the abundance (%) measurement results. Since the measured energy is not questionable, at least in its order of magnitude, and the isotopic shifts are confirmed by the accordance between ICP-MS and ToF-SIMS results, the suspects go to the ICP-AES data. It already seems that the quantity of nickel in the fuel should be less than 0.55 [g]. If this is the case, than probably the quantity of lithium is not correct either.

6.2.1. Direct Neutron Exchange

The direct exchange of a neutron between Li7 and a nickel isotope (58, 60 and 61), would be represented by the following hypothetical reactions:

- `Li7 + e + Ni58 -> Li6 + e + Ni59 + 1.75 [MeV]`
- `Li7 + e + Ni59 -> Li6 + e + Ni60 + 4.14 [MeV]`
- `Li7 + e + Ni60 -> Li6 + e + Ni61 + 0.57 [MeV]`
- `Li7 + e + Ni61 -> Li6 + e + Ni62 + 3.35 [MeV]`

These reactions combine the downward isotopic shift of lithium with the upward shift of nickel and give the lowest possible total energy for the two shifts for a complete upward shift of 0.55 [g] of natural nickel: 3.76 [MWh]. This energy would be 2.5 times the measured released energy. Any other set of reactions would liberate even more energy.
However the reports says: "From the ICP-AES analysis we find that there is about 0.011 gram of 7 Li in the 1 gram fuel.". To be precise on page 53 of the Report the weight percentage in the table is 0.0117 [g], which corresponds to 0.01093 [g] of Li7. If this latter number is correct, the fuel could provide only $9.382 \cdot 10^{20}$ atoms of Li7, which are enough to cause only less than 2.8% of the total Ni forward shift. Therefore, if the ratio of the weights of nickel and lithium is correct, the bulk of the upward isotopic shift of nickel must be due to something different from Li7.
In addition to the lack of Li7 neutrons in the charge, my opinion is that the reactions above are impossible. I haven't studied carefully the paper of Carl-Oscar Gullström (ref. [9]), which speaks about bound neutron tunneling, but I guess that this mechanism would be something exceptional as much as the "common" LENR mechanism, which does not entail bound neutron exchanges. I simply deem nil the probability that in the Hot-Cat fuel a second extraordinary mechanism is at work.

6.2.2. Separate Isotopic Shifts for Lithium and Nickel

The energies that would be released by nickel and lithium shifting separately are described in the next paragraphs, and have an average energy per isotopic shift which is clearly more than 1 [MeV]. As already stated, this means that, if the isotopic shifts in the taken sample are representative of what happened in the whole fuel, and the weights percentages of nickel and lithium in the fuel are correct, the energy produced by the separate shifts should have been substantially more than the measured energy.
My conclusion is that the sample for the ICP-AES analysis was not representative.

6.3. The Nuclear Reactions

6.3.1. First Stage

The First Stage is as usual for protium loaded metals:

```
0p: p+e -> pe (Hydronium)  +   Gp [MeV]
```

6.3.2. Second Stage

The series of reactions that lead to the isotopic shift of **lithium** are:

```
10e :Li6+ep              ->Li7    + neutrino +       (max)    6.47 [MeV] - Gp
                         ->He4    + t  + neutrino +  (max)    4.51 [MeV] - Gp
11e :Li7+ep+6.13[MeV]+Gp->He4    + H4 + neutrino +           0.00 [MeV]
                      H4 ->t      + n +                       3.39 [MeV]
11  :Li7+ep              ->Be8    + e +                      16.74 [MeV] - Gp
                    Be8 ->2 He4 +                            0.09184 [MeV]
```

In reaction 10 Li6 can transforms into Li7 or into He4 and tritium. In reaction 11 Li7 can turn into a couple of alpha particles liberating almost 17 [MeV].

Li7 has a magnetic dipole moment of 3.256424 [μN], larger than that of Li6, which is only 0.8220467 [μN]. This is the reason why Li7 should react more quickly causing the isotopic ratio between Li6 and Li7 to progressively grow.
If all 0.01093 [g] of Li7 initially present transformed into He4 by reaction 11, the released energy would be about 0.75 [MWh], half of the measured released energy. But at least some grains containing lithium seemed not to have completely reacted at the end of the 32 days run, as the ICP-MS analysis shows on page 53.

If Deuteronium were present lithium nuclei would undergo also these Second Stage reactions:

```
12e :Li6+ed+1.10[MeV]+Gd->He4    + H4 + neutrino +          0.00 [MeV]
                     H4 ->t      + n +                      3.39 [MeV]
12  :Li6+ed             ->Be8    + e +                     21.77 [MeV] - Gp
                    Be8 ->2 He4  +                          0.09184 [MeV]
13e :Li7+ed             ->Li9    + neutrino +       (max)   3.09 [MeV] - Gd
            (beta+n)Li9 ->2 He4  + n + e + antin. +(max)     .   [MeV]
            (beta)  Li9 ->Be9    + e +              (max)     .   [MeV]
13.1:Li7+ed             ->Be9    + e +                     16.18 [MeV] - Gd
```

The reactions with Deuteronium mentioned above were not present in the test of the Hot Cat because there was no deuterium nor it had been produced.

The Second Stage reactions that caused the upward isotopic shift in **nickel** are:

```
20e : Ni58+ep          ->Ni59 + neutrino + (max)       8.22 [MeV] - Gp
```

Part of the Ni59 decays by Electron Capture + a few Positron Emissions, becoming Co59. This isotope's half life is very long (76,000 [y]), while Ni59 can further react in the Second Stage LENR.

```
21e : Ni59+ep          ->Ni60 + neutrino + (max)      10.61 [MeV] - Gp
22e : Ni60+ep          ->Ni61 + neutrino + (max)       7.04 [MeV] - Gp
23e : Ni61+ep          ->Ni62 + neutrino + (max)       9.81 [MeV] - Gp
24e : Ni64+ep          ->Ni65 + neutrino + (max)       5.32 [MeV] - Gp
                 Ni65 ->Cu65 + e + antineut. + (max)  2.138[Mev]
```

Ni65 has a half life of 2.5175 [h].

```
24  : Ni64+ep          ->Cu65 + e +        (max)       6.94 [MeV] - Gp
```

Reaction 24 is much more likely than 24e because it does not require the participation of the electron. This is the reason why the presence of a significant decay of Ni65 was not detected during the test.
If reactions 20e through 23e had been responsible for the complete upward isotopic shift of 55 [g] of natural nickel towards Ni62, the energy released would have been around 13.5 [MWh], almost 9 times the measured energy.
This suggests that the percentage of Ni in the charge was less than 55%.

6.4. Power Rate During the Experiment

It is interesting to note that, if the main source of energy of the tested Hot-Cat were only the isotopic shifts of nickel and lithium the net power should have gradually decreased during the test, simply because the amount of reactants decreased to almost complete loss (as measured by the isotope analyses). This same comment has been made by Michael C. H. McKubre in his assessment of the second Independent Third Party Report (ref. [6]). McKubre wrote: "Rates of reaction are not expected to increase (one might state more strongly "are known not to increase") with near complete loss of fuel".

Even in the hypothesis that the real isotopic shifts of lithium and nickel were less drastic than those measured, the depletion of the reactants should have anyway caused a notable decrease in the produced power. Instead the net power production remained quite constant, and grew during the last 4 days. This means that the isotopic shifts of lithium and nickel are not the only source of energy.

These data suggest that there is something that can cause nuclear reactions not only in nickel and lithium, but also in other nuclei, releasing the energy always in relatively low energy photons.

My conclusion is that the power coming from the isotopic shifts of lithium and nickel progressively decreased during the test because of reactant depletion. The power that compensated the decrease came from nuclear reactions happening in the remaining 40% of the fuel (if the samples of the ICP-AES are representative). Either from the hydrogen nuclei or from the many other nuclei (like iron) present in the grains that did not contain lithium.

All this is not in contrast with the theory I am proposing. In fact the generation of the Hyd in the First Stage reactions prepares particles that can react with most nuclei (not only lithium and nickel) at a similar rate, since the Hyd are neutral particles that travel in all directions and couple with the nuclei only thanks to their magnetic properties. The production rate of the Hyd is not influenced by the kind of isotopes of the metal matrix (possibly each of the two tested target temperatures had its own rate of Hyd production).

It is precisely the depletion of lithium and nickel that caused the power increase in the last four days of the test (noted as well by Michael McKubre). In fact as lithium and nickel (their reacting isotopes) were decreasing, the Hyd were able to travel further and further away from their metal matrix source and couple with different nuclei. These other different nuclei were providing a higher average energy per reaction, so that the net power increased instead of decreasing.

All this matches also with the limitation imposed by Andrea Rossi to the experimenters not to carry on the test for more than 35 days, despite the repeatedly confirmed 6 months minimum fuel refill time. My guess is that the limitation was set in order to prevent reactions that can happen only when the isotopic shifts on lithium and nickel are completed, and that could possibly cause the emission of soft gamma rays, that would have required shielding of some sort, as it is the case for the low temperature E-Cat. Shielding would have added complications to the experiment and its evaluation, but most importantly, showing a reactor with no emissions whatsoever was a clever move that eliminated any possible comment on the safety of the reactors, even at their cores.

6.4.1. No Gamma Rays Means a Simpler Reaction Control

I think that part of the difficulty in controlling the reactions comes from the fact that, when present, the soft gamma rays produced by the LENR increase significantly the number of vacancies. This leads to a strong positive feedback that comes however with some delay from

the reaction start, and to which the control system must be ready to react. Therefore during the depletion of the isotopes of lithium and nickel the gamma radiation is absent and the control is easier and smoother. This could be an additional reason for the choice of limiting the test time to 35 days.

6.5. Role of Lithium in the Hot-Cat

I think that the role of lithium in the Hot-Cat is related to its nuclear reactions only fortuitously, in fact its essential contribution comes from its "physical-chemical" properties that allow a very good First Stage.
Lithium seems actually to have many roles in the Hot-Cat:

- it helps carrying the protons in the hydride/s,
- it enhances the number and the stability of the vacancies in the nickel metal matrix,
- it participates in the Second Stage LENR,
- it may be helping absorb and break up the energetic Gp photons through its mobility inside the metal matrix.

6.6. Magnetic Coupling

6.6.1. Ni59

Ni59 is radioactive, with a half-life of 76,000 years, and decays almost exclusively via electron capture. The branching to positron emission is only 0,000037%. Therefore if this isotope remains in the charge only as traces it will not cause significant gamma radiation (for a 0.55[g] Ni charge ...).

6.6.2. Ni61

Ni61 is the only stable Ni isotope with a magnetic dipole moment. Therefore Ni61 should disappear more quickly than the other isotopes, because it should better couple with the Hydronions. The complete absence of Ni61 in the ash seems to confirm this detail of the theory.
The other isotopes could have magnetic moments of higher order, but no data are available to me.

6.6.3. Ni62

Ni62 is not depleted. The nuclear (fcc) structure of Ni62 is sort of "perfectly symmetric", in fact it possesses the highest binding energy per nucleon. That makes its magnetic moments exactly equal to 0. This is the reason why Ni62 does not couple with the Hyd, and stops the isotope shift progression.

6.6.4. Ni64 is the Source of Copper 65

The experimental results say that Ni64 is depleted by the LENR. Thus I gather that Ni64 must have a quadrupole or higher magnetic moment that allows it to couple with the Hyd.
Ni64 reacts mainly through reaction 24 becoming Cu65. In some rarer occasions it turns into Ni65 (reaction 24e), which decays to Cu65 with a half-life of 2.517 [h].
I think this is the origin of the isotope shift described in the Rossi-Focardi paper "A new energy source from nuclear fusion" (ref. [13]) . In that report the natural isotope ratio between Cu63 and Cu65, equal to 2.24, was found to have shifted to 1.16 in the ash. I suggest that that shift was due to the addition of Cu65, in an amount exactly equal to the Ni64 that reacted.

6.7. Why only Nickel and Lithium were Detected on the Ash Particle Surface

The generation of Hdy needs the movement of Ni vacancies, and this takes place mostly near to the particles' surfaces. Therefore, since Hyd were continuously generated during the test, after 32 days the nickel matrix had incorporated the rest of the elements that were initially dispersed inside it and that were not participating in the vacancy movements. This is the reason why the only elements that were found on the particle analyzed in Fig. 9 of the report [6] are almost only Li, Na, (Si28?), and Ni.

Probably some Aluminium was transformed into Silicon. However, in presence of Hydrogen, volatile Silane (SiH4) forms and flies away from the unsealed reactor.

6.8. Start Up Time of the E- and Hot-Cat

The tens of minutes needed to start the H/E-Cat reaction are probably due not only to the time necessary to sufficiently load with hydrogen the metal matrix, but also to the time needed to develop a sufficient population of vacancies.

7. Interpretation of Other Experimental Results

7.1. Yasuhiro Iwamura

Iwamura-san of Mitsubishi Heavy Industries (MHI) so far has worked exclusively with deuterium.

The transmutations that Iwamura declares in ref. [7] to have obtained are:

$$^{133}_{55}Cs \xrightarrow{4d(2\alpha)} {}^{141}_{59}\mathrm{Pr}$$

$$^{88}_{38}Sr \xrightarrow{4d(2\alpha)} {}^{96}_{42}Mo$$

$$^{138}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{150}_{62}Sm$$

$$^{137}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{149}_{62}Sm$$

$$^{44}_{20}Ca \xrightarrow{2d(\alpha)} {}^{48}_{22}Ti$$

$$^{184}_{74}W \xrightarrow{2d(\alpha)} {}^{188}_{76}Os$$

$$^{182}_{74}W \xrightarrow{4d(2\alpha)} {}^{190}_{78}Pt$$

They seem to happen all over the Periodic Table.

7.1.1. Cs133 to Pr141

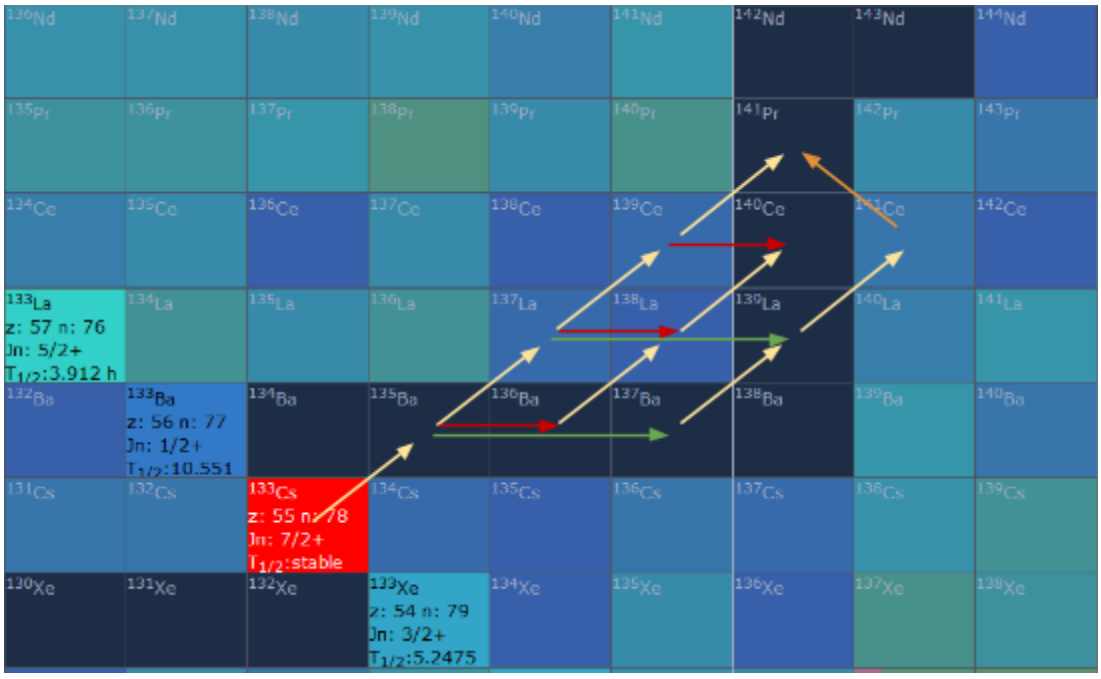

Fig. 3. Some of the Second Stage Reactions involved in the "Cs133-Pr141 experiment".

The transmutation of Cs133 up to Pr141 should be due to this set of main reactions:

```
30 : Cs133+ed        ->Ba135 + e + (max)            12.405 [MeV] - Gd
32 : Ba135+ed        ->La137 + e + (max)            11.915 [MeV] - Gd
```

La137 undergoes electron capture to Ba137 with a Q value of 580.549 [KeV].

```
33 : La137+ed        ->Ce139 + e + (max)            12.434 [MeV] - Gd
34 : Ce139+ed        ->Pr141 + e + (max)            11.701 [MeV] - Gd
```

Ce139 undergoes electron capture mainly towards an excited La139. Q = 278.381 [KeV]

Other reactions are:

```
35 : Ba136+ed        ->La138 + e + (max)            10.259 [MeV] - Gd
```

La138 is practically stable (half life = $1.02 \cdot 10^{11}$ [y]).

```
36 : Ba135+ed        ->Ba137 + neutrino + (max)     13.006 [MeV] - Gd
37 : Ba137+ed        ->La139 + e +  (max)           12.132 [MeV] - Gd
38 : La139+ed        ->Ce141 + e +  (max)           12.132 [MeV] - Gd
...
```

In fig. 3 all diagonal shifts are due to the "absorption" of a deuterium in the nuclei (Z+1, A+2), therefore they do not need the participation of the electron and are much more likely than the horizontal shifts by two units (Z+0, A+2).

The gamma emissions measured by Iwamura seem to suggest that:

- **Gp = 1,745 [keV]**
- **Gd = 1,445 [keV].**

The signal at 1,445 [Hz] is much stronger than any other, hence it could be Gd. Then there should be another higher frequency, Gp, generated by the formation of Hydronions due to the

presence of protons liberated by reaction 4.2, with a much lower signal. The only other higher frequency is 1.745 [Hz], and the ratio between the two is $3.0 \cdot 10^{-4}/3.5 \cdot 10^{-3}=8.6\%$. There is another signal at 1,109 [Hz] which has a strength in between the two. It should be the highest fractionation frequency of the metal matrix used, and should come from all the Second Stage reactions above. In fact the sum of the counts of the frequencies 1.109, 605, 578.9, 507.4 [Hz] amounts to $2.5 \cdot 10^{-3}$ [cps], about 60% of the count at 1.445 [Hz]. Other interpretations of the frequencies are also possible.
Such a high Gp would mean that equation 1e needs actually a stimulus of 303 [keV] to take place. This could be the reason for the absence of deuterium in the Hot-Cat test and for the difficulty in starting LENR hydrogen loaded systems.
In the case of deuterium loading, in presence of Deuteronium, if the sample is illuminated with gamma rays of 1.586 [MeV] the production of neutrons should be stimulated through reaction 4e.

7.1.2. Sr88 to Mo96

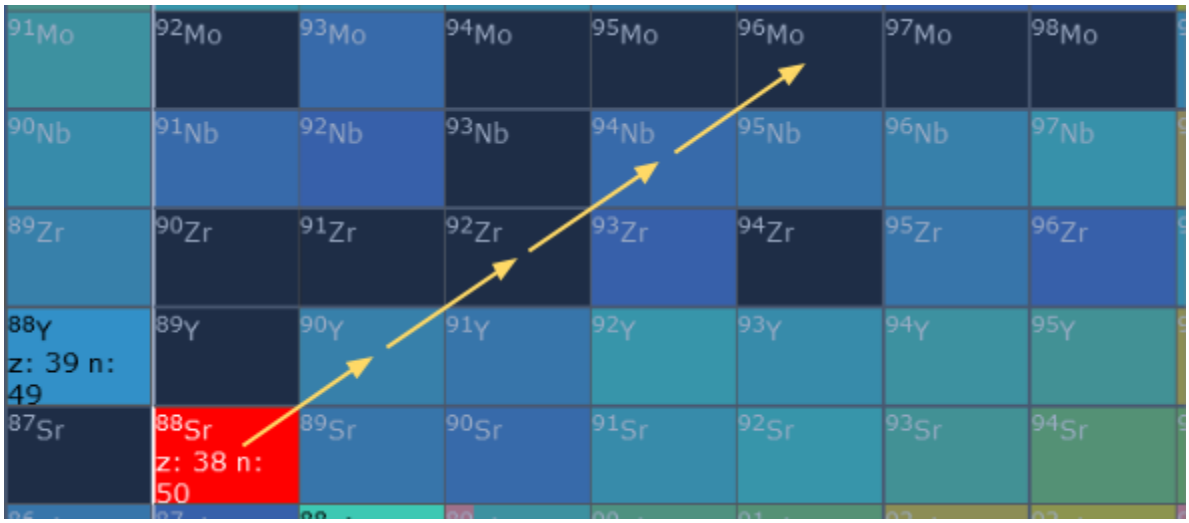

Fig.4. Possible straight reactions path between Sr88 and Mo96.

In this case the among the products there is Y90, which decays beta 100% with a Q of 2,278.7 [keV] and a half life of 64 [h]. There should be a signal of this beta decay.
The other unstable nucleus in the straight reaction line is Nb94, which decays beta as well and has a half life of $2.03 \cdot 10^{4}$ [y]. This nucleus should generate a gamma signal as Y90, but a bit fainter.
The three frequencies of 1,445, 1,745 and 1,109 [keV] should be present as in all other experiments with deuterium loading.

7.1.3. W184 to Os188

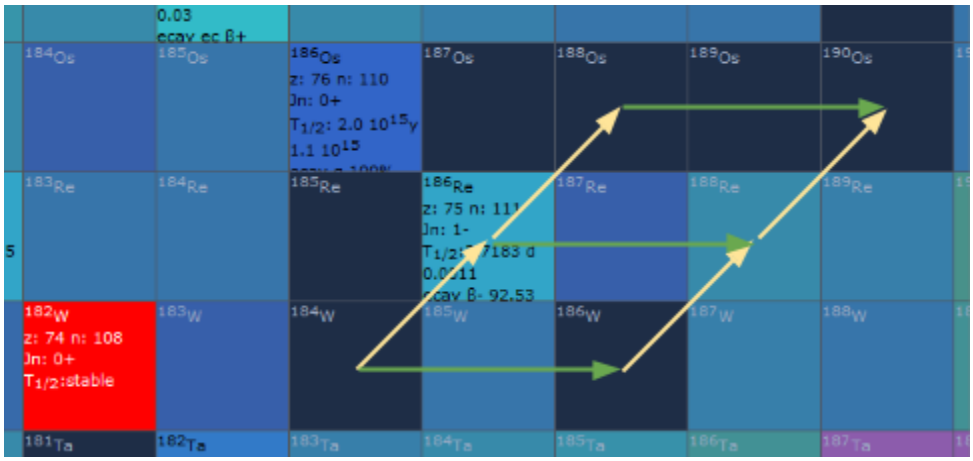

Fig. 5. W184 to Os188.

The Second Stage LENR on W184 should lead mainly to Os188 as shown in Fig. 5. Os190 can be reached only through reactions that involve the electron and that are much less likely.

7.1.4. W182 to Os190

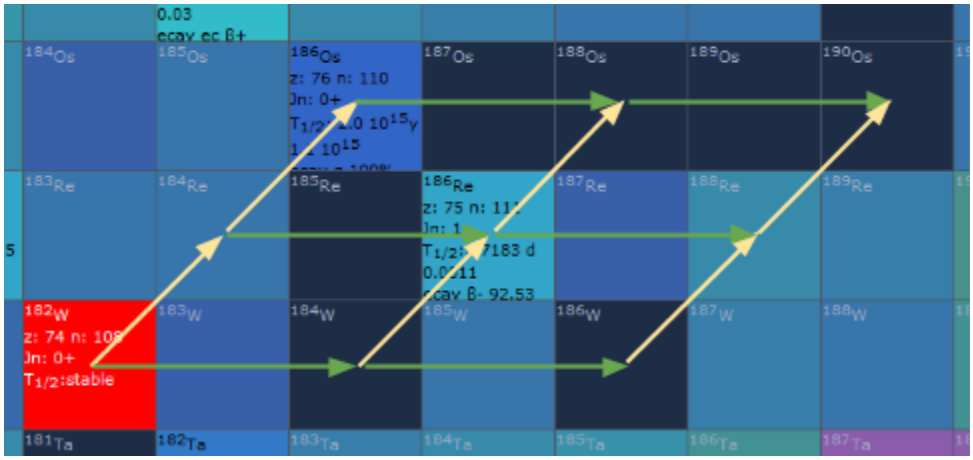

Fig. 5. W184 to Os188.

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7.2. Gas Production by Hideki Yoshino, Eijiro Igari and Tadahiko Mizuno

The experiment in ref. [2] by Hideki Yoshino, Eijiro Igar and Tadahiko Mizuno produces an every increasing quantity of a gas with mass 2, whereas the partial pressure of a gas with mass 3 initially increases but, after peaking decreases progressively. Free neutrons are also sporadically emitted.

Applying the theory described, it appears that the most important reactions taking place in this experiment are:

First Stage:

```
0d: d+e -> de (Deuteronium)+   Gd [MeV]
```

Second Stage:

```
 4.1: d+ed              ->He4 + e  +              22.825[MeV] - Gd
 4.2: d+ed              ->t   + ep +               4.03 [MeV] - Gd
               ep + Gp  ->e   + p (Hydrogen atom)
 6.1: t+ed              ->He5 + e +               15.83 [MeV] - Gd
                   He5  ->He4 + n +                0.735[MeV]
(3e : d+ep              ->t   + neutrino + (max)   5.475[MeV] - Gp)
 3  : d+ep              ->He3 + e +                4.472[MeV] - Gp
 5  : t+ep              ->He4 + e +               18.792[MeV] - Gp
```

The Deuteronium produced by the First Stage reacts in the Second Stage reactions 4.1 and 4.2, producing He4 and tritium. The main decrease of the mass 4 gass is due to the absorption of the D_2 gas into the nickel powder, while the production of He4 can not clearly balance the decrease.
The increase in gas of mass 3 is not only due to reaction 4.2, but also to reactions 3 and 3e, which use the fraction of Hydronium produced by reaction 4.2 that does not decomposes. Part of the gas with mass 3 should in fact be He3.
Reaction 4.2 is the main source of the constantly increasing molecular hydrogen, because when the Hydronium (ep) is hit by photons with at least the Gd energy, it decomposes into electron and proton;and the proton rapidly combines with another proton to form molecular hydrogen.
Reaction 6.1 is the source of the detected neutrons. This energetic reaction can take place only when enough tritium is trapped into the metal matrix.

8. Safety Concerns

Since the Hydronions are neutral "pseudo-particles" can travel freely through matter and change not only the isotopes of the nuclei, but also the atomic number (Z), their presence should be of concern for living beings.
Detecting hydronions is still not possible. Therefore their Mean Free Path (MFP) is not known. Experiments suggest that the MFP is not very long, but it could depend strongly on the material the Hydronions cross.
The effects depend on how many Hydronions are generated and when the power increases the effects clearly increase. So far only a handful of reactors seem to have produced powers higher than a few Watt.
Before adopting reactors able to produce [kW] of power I think it should be better to find a way to measure the MFP and to prevent the escape of any Hydronion from the reactors.

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